AD-A198 301

Final Report

AV-FR-85/829

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INDIVIDUAL LIFT DEVICE (ILD) PACKAGEABILITY EVALUATION

Contract No. DAAJ09-84-C-B321

Submitted to

U.S. Army Aviation Systems Command
(AVSCOM)
St. Louis, Missouri

August 1985

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By

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SUMMARY

This report gives the results of a packageability study performed under fixed price contract number DAAJ09-84-C-B321 for the U.S. Army Aviation Systems Command, St. Louis, Missouri, for reduction in erection time of an Individual Lift Device (ILD). Although budget constraints prevented complete modification of this vehicle to an optimum configuration, the constraints have been quantified sufficiently to permit prediction of geometry requirements for any similar folding wing system. The vehicle (known as the Roc prototype) could be modified to a working system in approximately 100 more manhours of effort, and to an optimized configuration with approximately 300 manhours of effort.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

1. INTRODUCTION

This document constitutes the final report for a study of the feasibility of incorporating self-contained folding ribs into an existing, collapsible, single-place aircraft. This aircraft, named the "Roc", was previously developed under contract to another agency for use as an exfiltration vehicle by a "non-pilot" with a minimum of prior training. Additional requirements for this vehicle included a rapid erection time, low noise profile, and a range of 100 miles in a 20-mph headwind. The prototype Roc is shown in Figures 1 through 4.

2. BACKGROUND

The original prototype was developed from a scaled, folding model (see Figures 5 and 6) and flight model (Figure 7) to verify the erection and stability and control concepts.

Correlation of flight test data of the flying models to the full-scale prototype was found to be excellent, with handling, stability, and control characteristics of the prototype improved over those demonstrated by the models.

Correlation of the folding characteristics of the full-scale Roc to those demonstrated by the folding model was reasonably good, although scale effects tended to reduce ease of erection somewhat, particularly in the critical areas influenced by sail tension. However, a reasonable effort produced a prototype that incorporated essentially all the foldability features of the model, with the exception of the self-contained, folding ribs. Budgetary limits for the development and flight test program resulted in a decision to reduce the scope of the initial effort by using removable battens in lieu of the integral, folding ribs demonstrated on the scale model. While the removable battens simulated the aeroelastic characteristics adequately, eight to nine of the 14 minutes required to set up the Roc prototype involved the insertion of the 28 removable battens. It was therefore deemed highly desirable to incorporate the folding ribs into the prototype in order to fully demonstrate the Roc concept.

As the funds available from the original sponsor for this effort were sufficient only to complete the flight test program of the single-place version and the preliminary design of the two-place version, additional funds were sought to perform the following:

1) Modify the airframe and main wing sail (covering) to incorporate integral, folding ribs and appropriate sail tensioning devices.
2) Modify the landing gear to permit telescoping of the axle to reduce the maximum folded width to within that of the propeller (five feet).
3) Modify the tip bow to permit proper placement during tip spread without excessive operator effort.

Initial cost estimates for these efforts were $45,000 at (then current) burdened rates.

Interest was expressed by various military groups (including the U.S. Army Special Forces at Fort Bragg) in the concept of using Roc as an infiltration - exfiltration vehicle. Subsequent discussion with the DRSAV Office of AVSCOM at St. Louis resulted in negotiation of a fixed price contract of $30,000 to perform the above work. While this amount was less than our original estimate, it was believed that the goal could be achieved if no unforeseen problems arose.

3. RESULTS OF STUDY

3.1 Telescoping Landing Gear

As can be seen in Figures 8 and 9, the telescoping landing gear modification was accomplished with little difficulty. When extended, the landing gear's overall dimension is 6-1/2 feet, center to center. By use of a simple, one-piece lifting device and removal of a "Pip-pin", the landing gear are slid outward until alignment of a second hole permits reinstallation of the "Pip-pin."

This effort was accomplished prior to completion of the Roc flight test program and has been flight tested to drop heights of 4 feet in addition to being analyzed to tolerate a 4 "G" limit landing load without permanent deflection.

3.2 Leading Edge Former

The leading edge in the original prototype Roc was shaped by the forward sections of the removable battens, with a .014-inch thick Mylar sheet inserted into a leading edge pocket to span between the battens. In the folding rib version, the rigid portion of the ribs must stop behind the leading edge spar to allow nesting of the spars around the motor, prop and fuselage. Therefore, a shaped leading edge former is required that would span the gaps in the ribs both chordwise and spanwise, with adequate stiffness to maintain the airfoil contours in the flight configuration, yet would have enough flexibility to permit deformation during folding and allow the ribs to nest behind the leading edge and local indentations in the front of the leading edge.

Several types of composite leading edge were tested (Figure 10), with the best material found to be a laminate of (1/2 mil) Mylar/carbon/Kevlar/carbon/ Mylar. The Mylar created a snag-free surface which facilitated installation of the leading edge into its pocket, while also minimizing abrasion of the carbon in flight (caused by shifting of the sail in response to load changes and engine vibration). The unidirectional carbon-fiber-reinforced epoxy laminations are oriented with the fibers running spanwise to maximize the stiffness required to bridge between ribs. The innermost ply of unidirectional Kevlar-reinforced epoxy is oriented with the fibers running chordwise to provide good toughness and binding of the graphite plies, allowing reasonable flexibility in the chordwise direction to permit rib folding.

Installation of the composite leading edge is shown in Figure 11.

3.3 Folding Ribs

Folding ribs were fabricated from welded aluminum to facilitate changes and minimize mold fabrication time. For production, these ribs should be made from composites to minimize weight and fabrication time.

To save labor costs the tubular aluminum battens from the prototype were modified to form the upper and lower caps of the ribs, with smaller aluminum tubes welded in place as the shear members of the truss (see Figure 12).

There are seven ribs per side, plus a tip bow. The fourth rib out on each side serves as a compression strut for the wing brace wires, and has a large diameter tube integral to the rib at the chordline (to the left in Figure 12).

A hinged joint was installed just aft of the forward spar (Figure 13), just forward of the aft spar, and just aft of the aft spar (Figure 14). The hinging axis is offset from the rib plane, the ribs being normal to the sail surface, while the hinge axes must be parallel to the respective spar hinges to permit folding of the wings. The folding trailing edge of the rib behind the rear spar is critical to the foldability of the covered wing, and this element is discussed in more detail in Appendix 1.

A prototype rib was load tested to the ultimate loads (1.5 x limit loads) associated with V_{ne} (93 mph) and a 24-fps sharp-edged gust with a 1.5 factor of safety, and to V_a (57 mph) with a +5.33, - 2.67 G maneuvering load, also with a 1.5 multiplier. The test process is documented in the accompanying videotape and in Appendix 3. The ribs were shown to be over-strength, with no permanent deformation occurring, even at ultimate loads. A CL of .74 was chosen for the test because the distribution of air loads represented a worst case for the bending of the rib.

Figures 15 through 20 depict the folding operation showing the nesting of the ribs. As can be seen from the photographs, the hinging and nesting of the ribs with the sail removed formed a fairly compact package and represented a large savings in erection time. However, a problem arose in achieving full collapse of the covered wing in the full-scale version (see Figure 21). The cause of the problem has been determined to be the greater shear stiffness of the 3.8 oz.-per-square-yard, stabilized Dacron sailcloth. This greater shear stiffness effectively prevented any elongation of the tension line running diagonally from the forward tip of the sail to the aft inboard corner. As a result, the tension webs[1] in the sail (see Figure 22) were pulled outboard in the aft root section and against the adjacent rib, thus resisting complete collapse of the wing.

The length of the folding, trailing edge segment of the ribs needs to be increased by approximately one foot, which would require relocation of the aft spar one foot further forward relative to the front spar. Also, the spanwise spacing of the ribs near the root should be increased by about 50% (Appendix 1 gives the details of the geometry quantifying this probiem).

As can be seen in Figure 23, the longer trailing edge rib segment would permit the aft tips of the ribs to remain always attached to the sail trailing edge as intended, instead of pulling away from the sail as currently is the case, complicating the folding/erecting process. Two alternative proposed solutions to the above problem are discussed in Appendix 2.

3.4 Other Changes

Other modifications required during this project were as follows:

1) Increased spring tension in the main erection springs (see Figure 24) to accommodate the added weight of the rib assemblies
2) Extension of the aft spar hinge brackets to equalize folding lengths and to accommodate the added width associated with the folded ribs (see Figure 25).

A video log documentation of the construction and testing process has been compiled on 1/2" VHS video tape and two copies of this tape have been submitted with this report.

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[1] These webs were required to maintain smooth contour on the upper and lower surface of the wing, since the ribs are not integral with the sail, as were the battens.

A complete set of prints of the engineering drawings required to modify the sail and fabricate the ribs have been supplied to the cognizant technical office (AMSAV-NC) with six copies of this report.

4. CONCLUSIONS

It is believed that the feasibility of this folding wing concept has been demonstrated and that the problems which have been incurred during this study could have been resolved on the prototype vehicle had adequate funds been available to permit redesign and modification of the structure as described above. It is believed that the problem encountered and its solution are adequately quantifiable (reference Appendix 1) to permit design of the two-place Roc or production versions of the single-place Roc at very low technical risk.

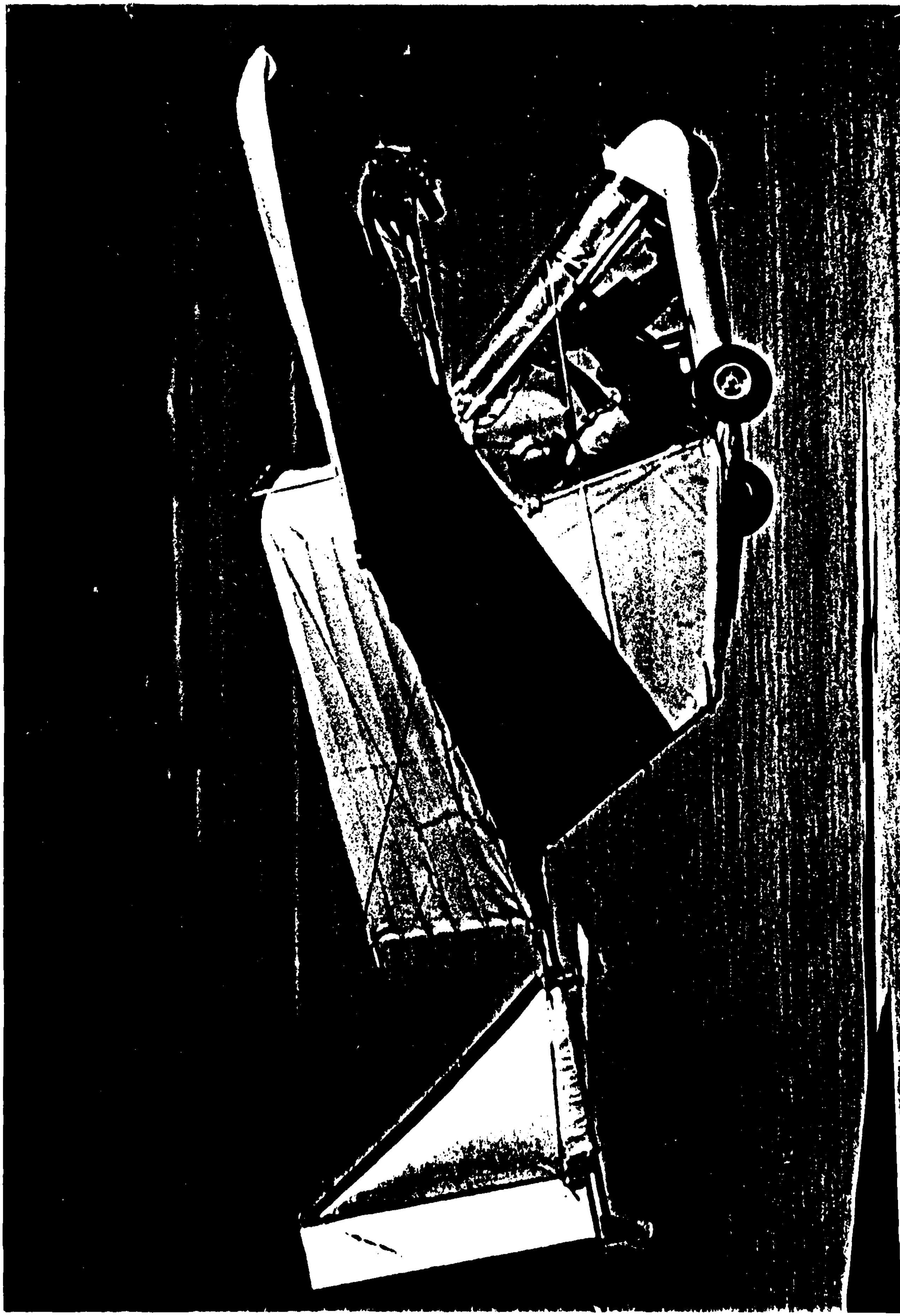


FIG. 1. SIDE VIEW - ROC IN FLIGHT.

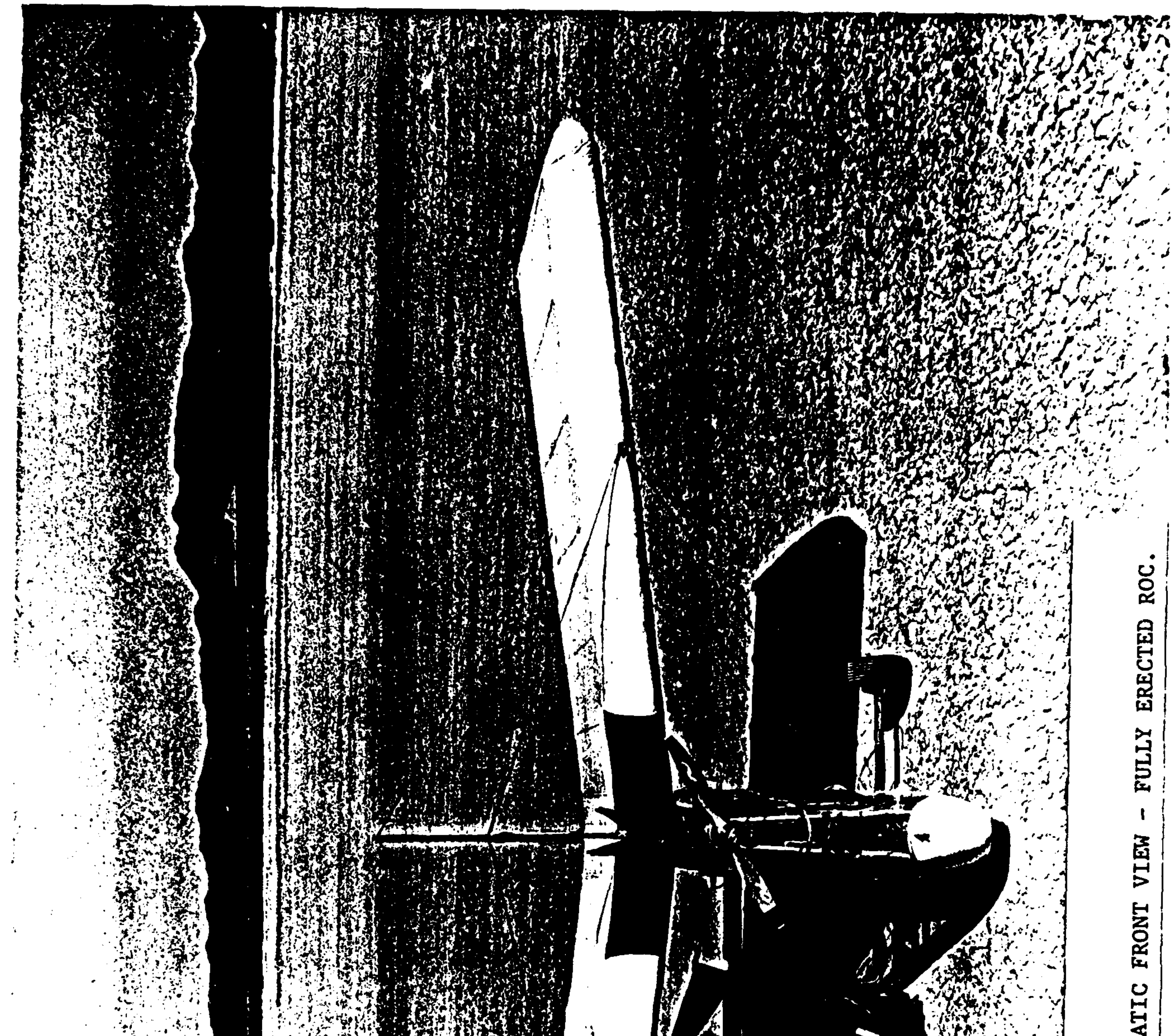


FIG. 2. STATIC FRONT VIEW - FULLY ERECTED ROC.

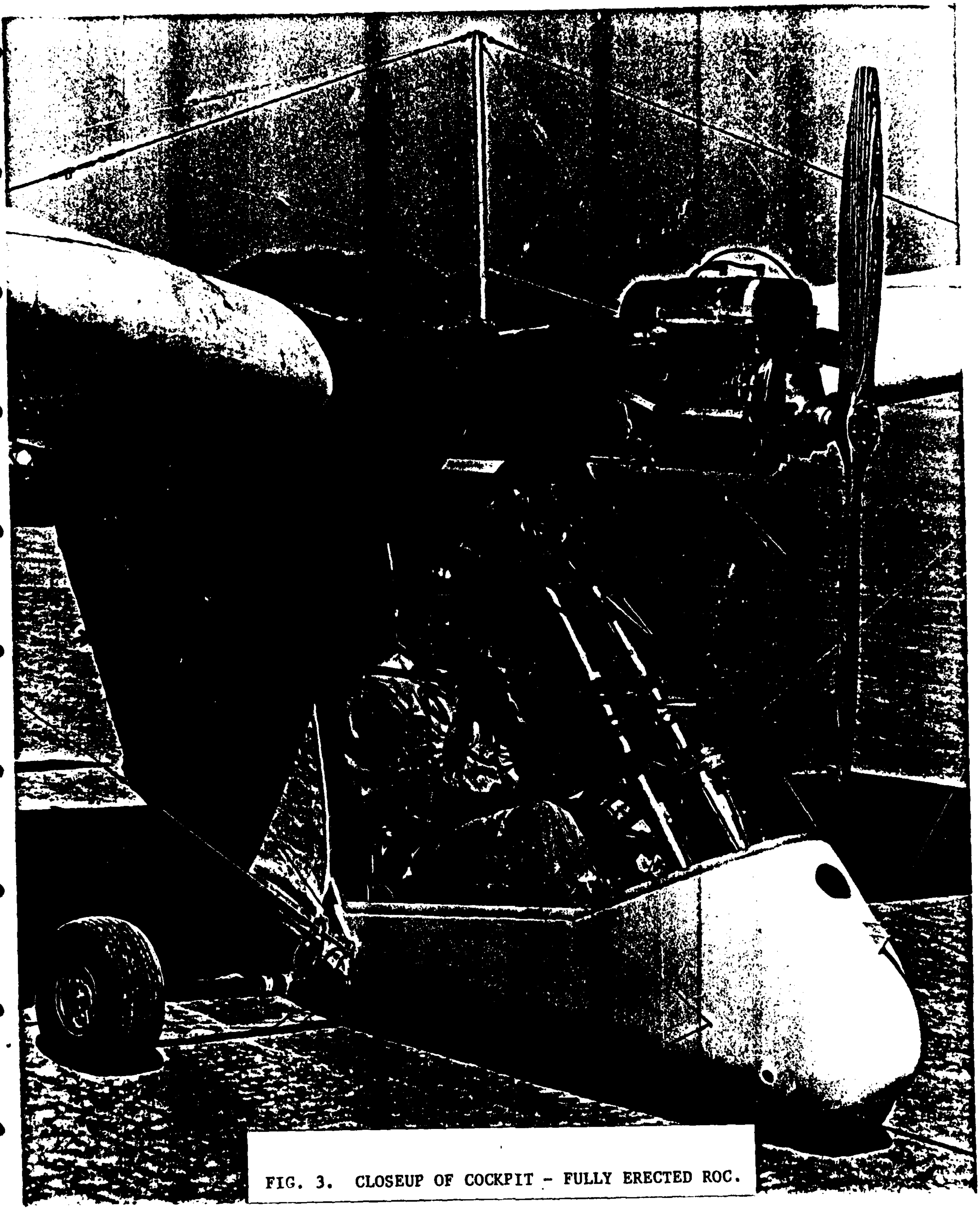


FIG. 3. CLOSEUP OF COCKPIT - FULLY ERECTED ROC.

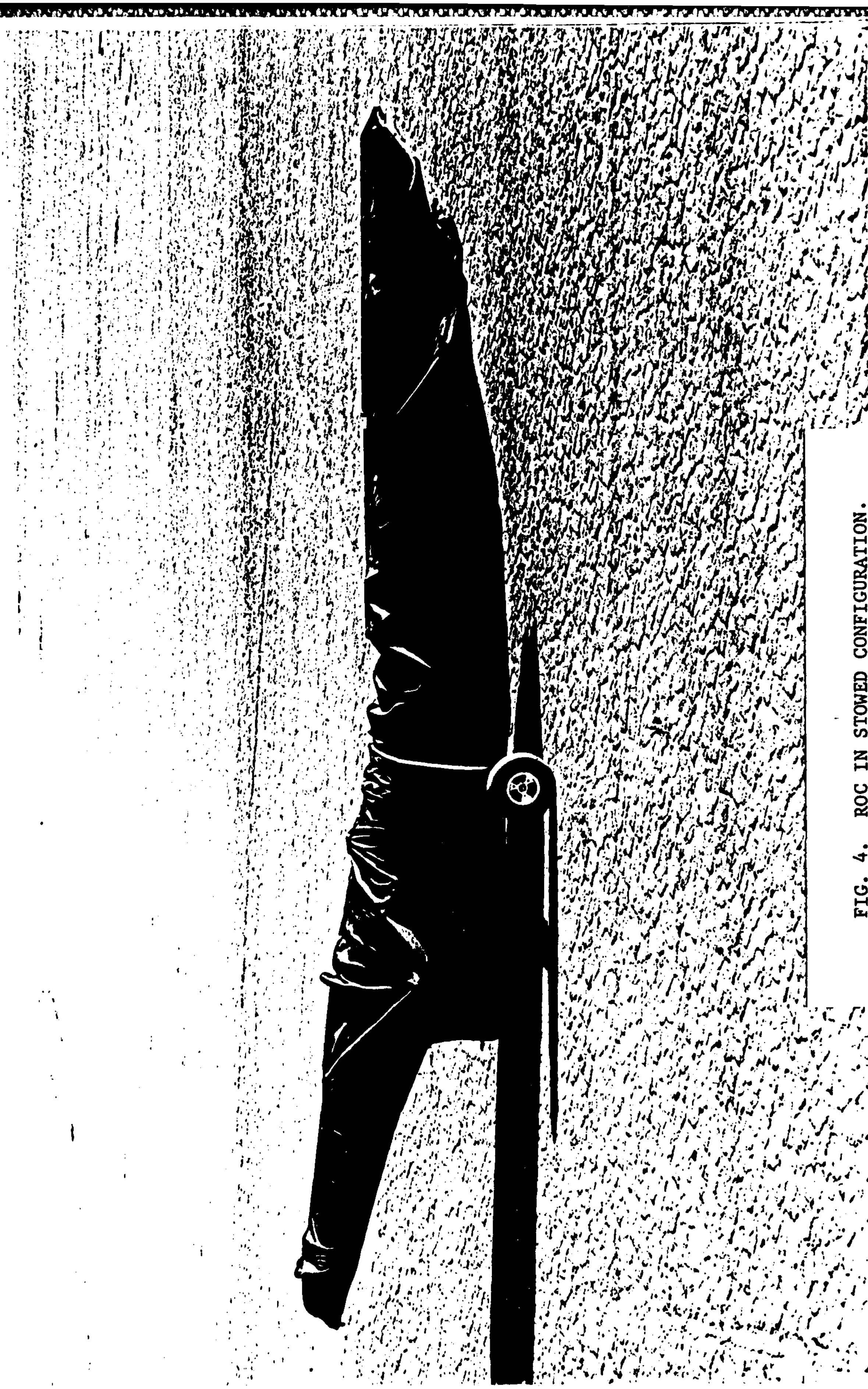


FIG. 4. ROC IN STOWED CONFIGURATION.

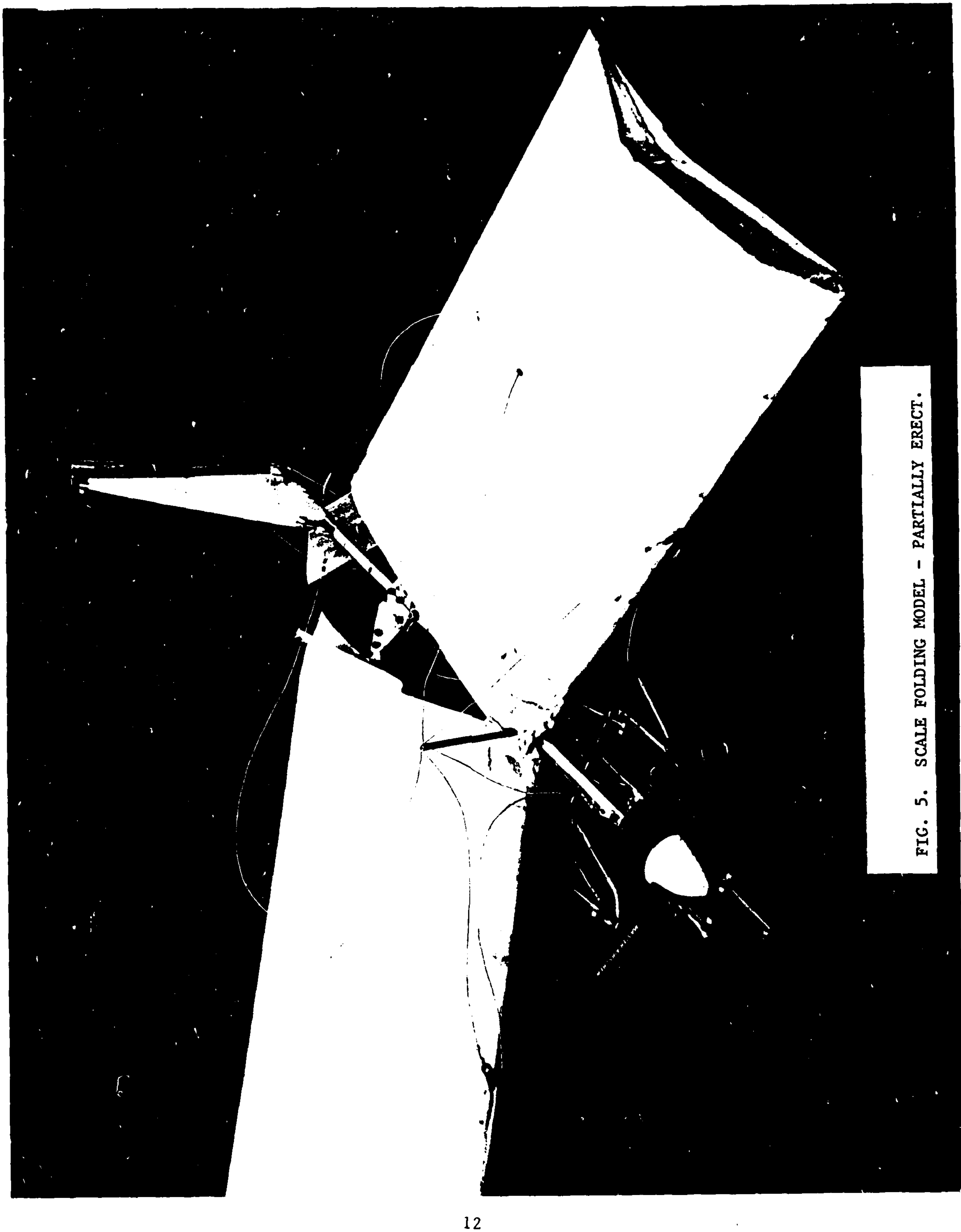


FIG. 5. SCALE FOLDING MODEL - PARTIALLY ERECT.


MASTER AIRSCREW

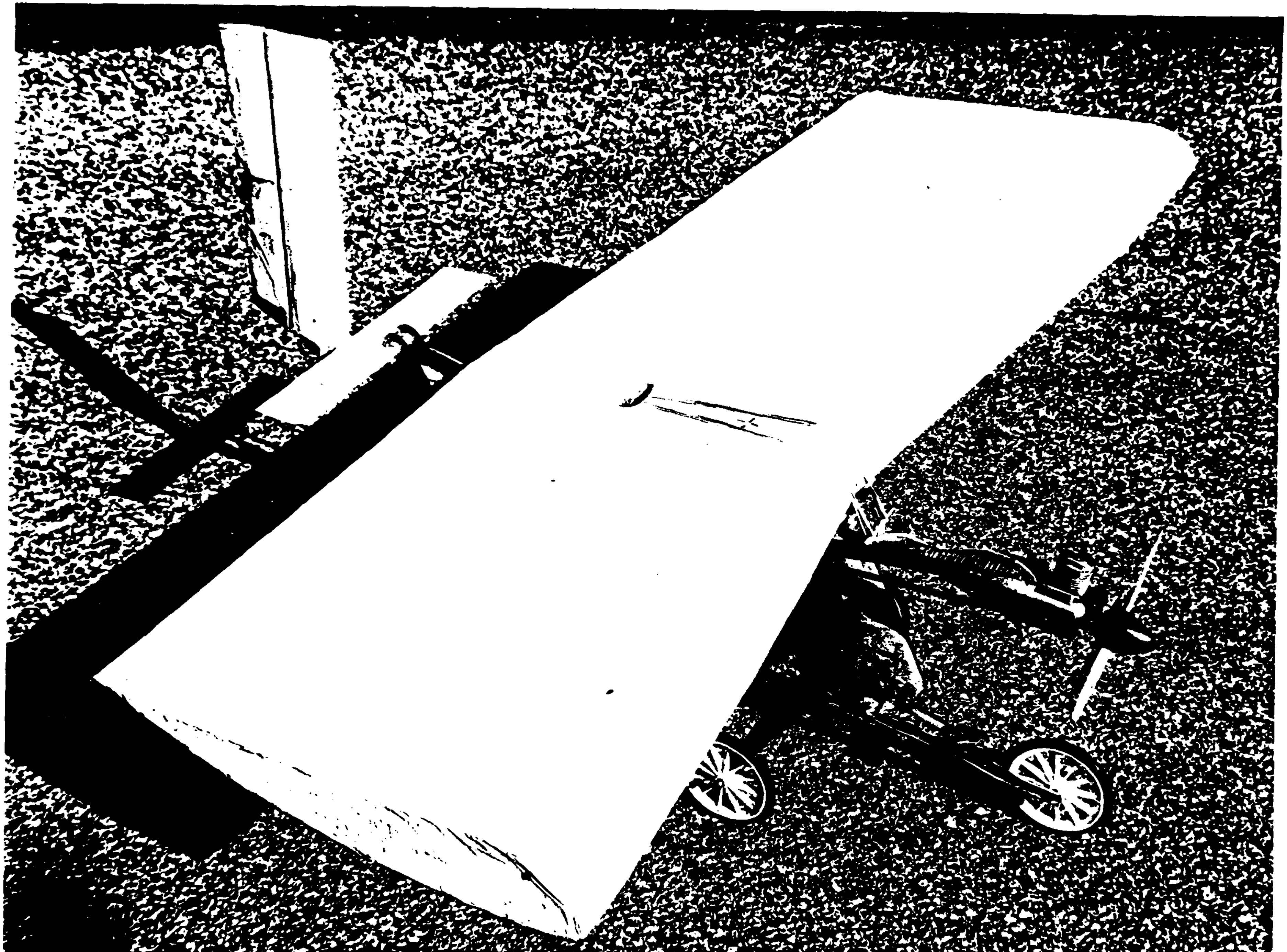


FIG. 7. 1/4 SCALE ROC FLIGHT TEST MODEL.

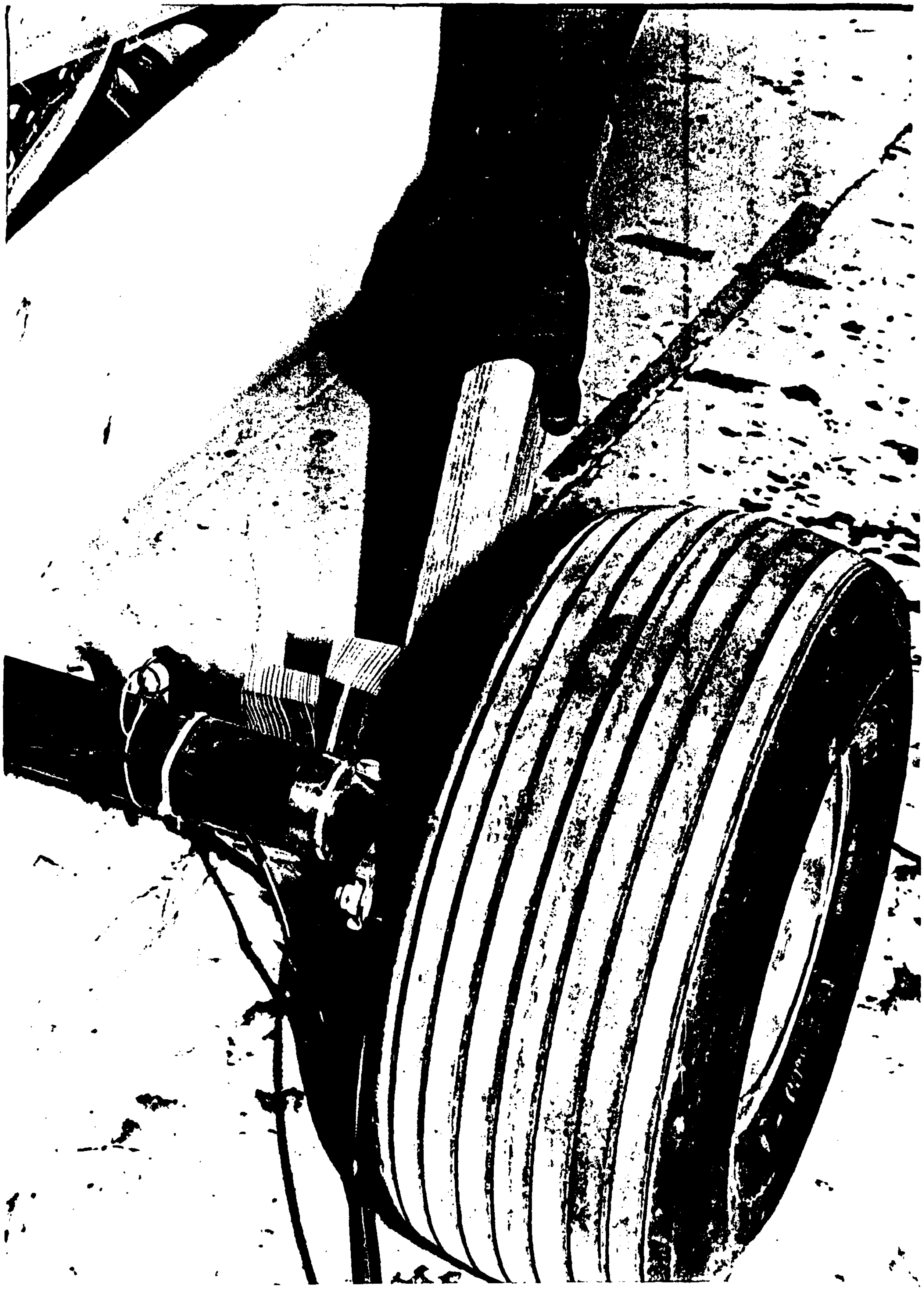


FIG. 8. LIFTING OF WHEEL TO EXTEND AXLE.

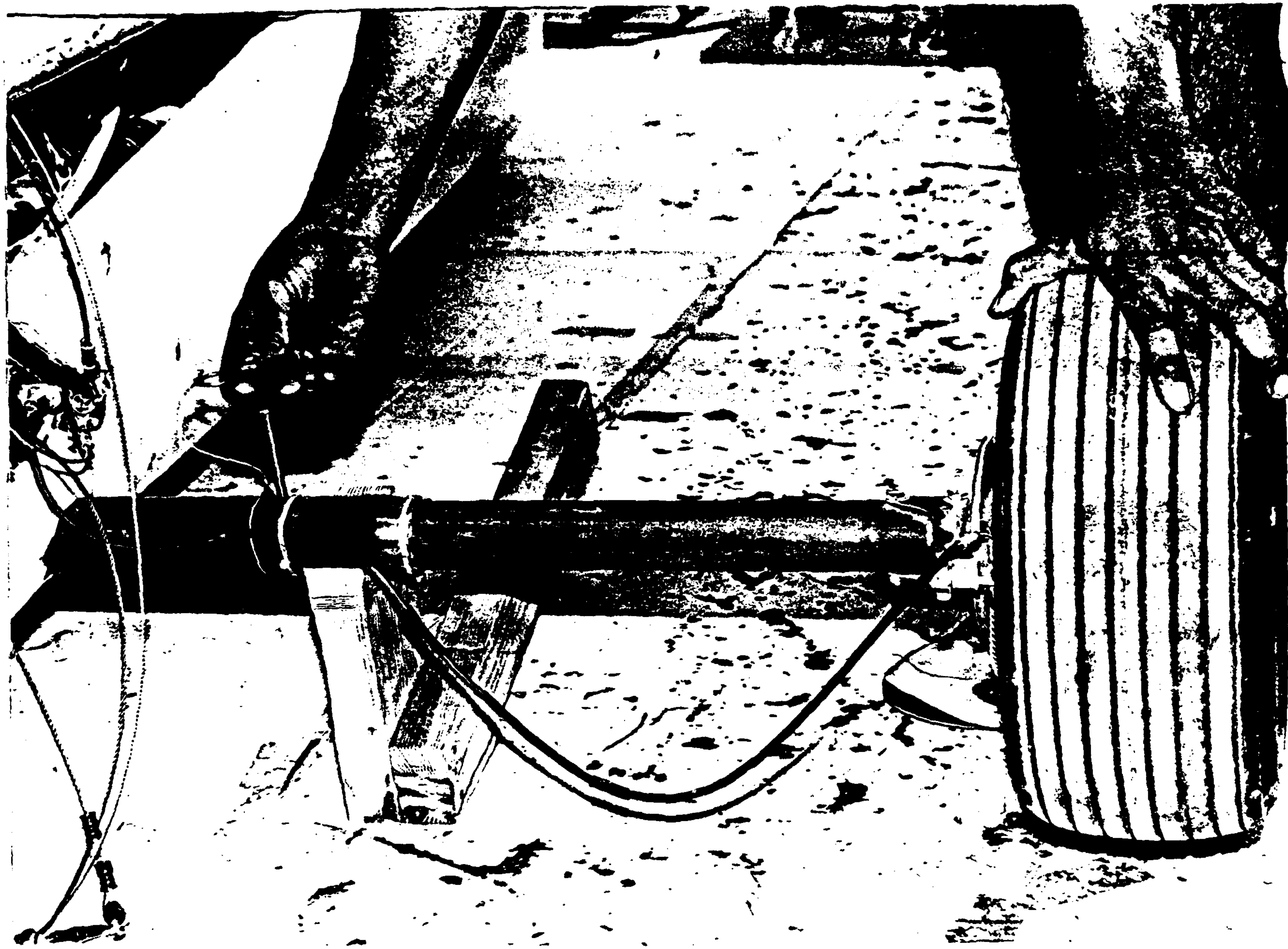


FIG. 9. REPLACEMENT OF QUICK-RELEASE PIN AFTER AXLE EXTENSION.

FIG. 10. VIEW OF KEVLAR/KEVLAR/CARBON, CARBON/KEVLAR/CARBON, AND MYLAR/CARBON/KEVLAR/CARBON/MYLAR LEADING EDGE FORMER SAMPLES.

FIG. 11. INSTALLATION OF FLEXIBLE, MYLAR/CARBON/KEVLAR/CARBON/MYLAR LEADING EDGE FORMER INTO SAIL POCKET.

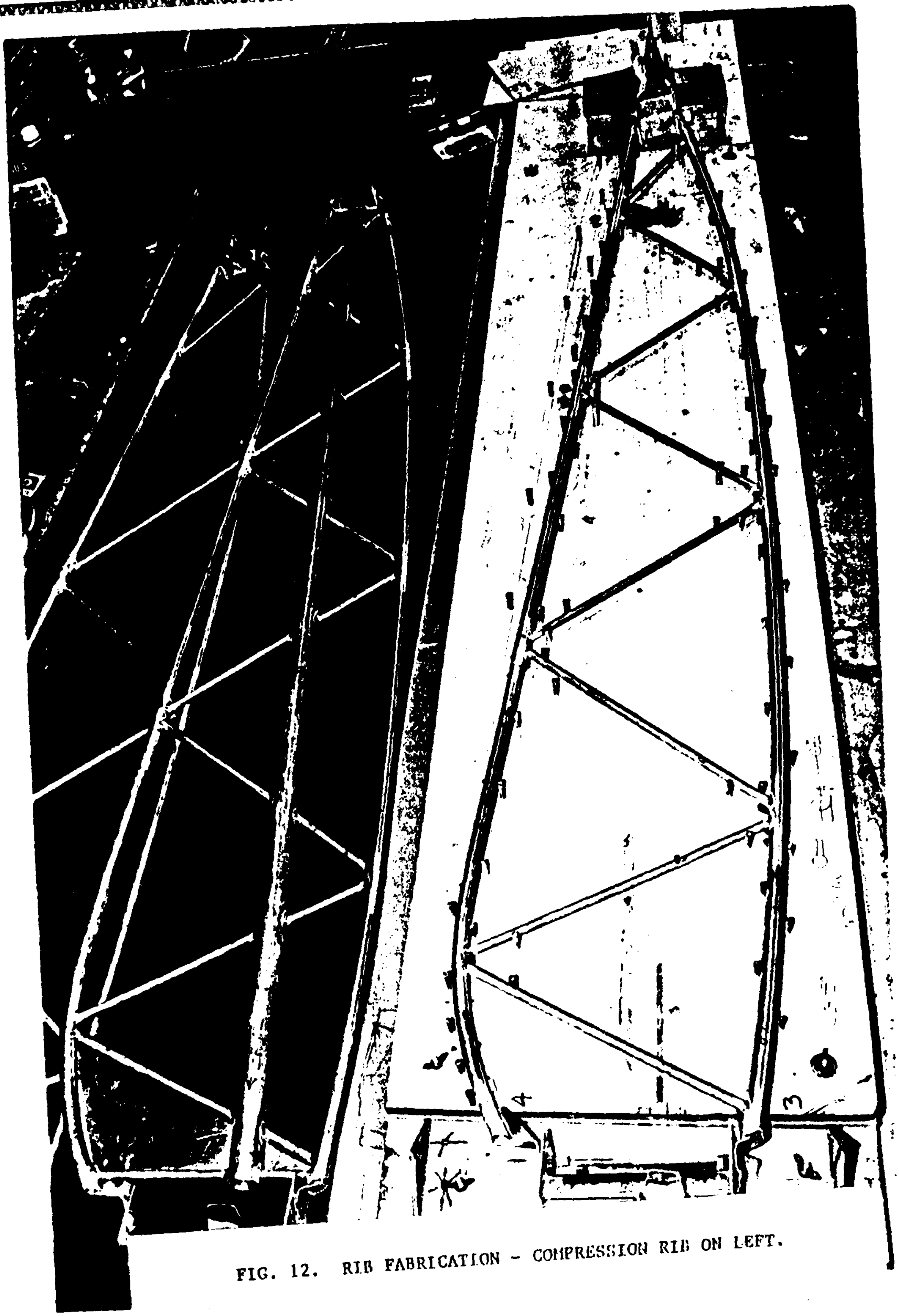


FIG. 12. RIB FABRICATION - COMPRESSION RIB ON LEFT.

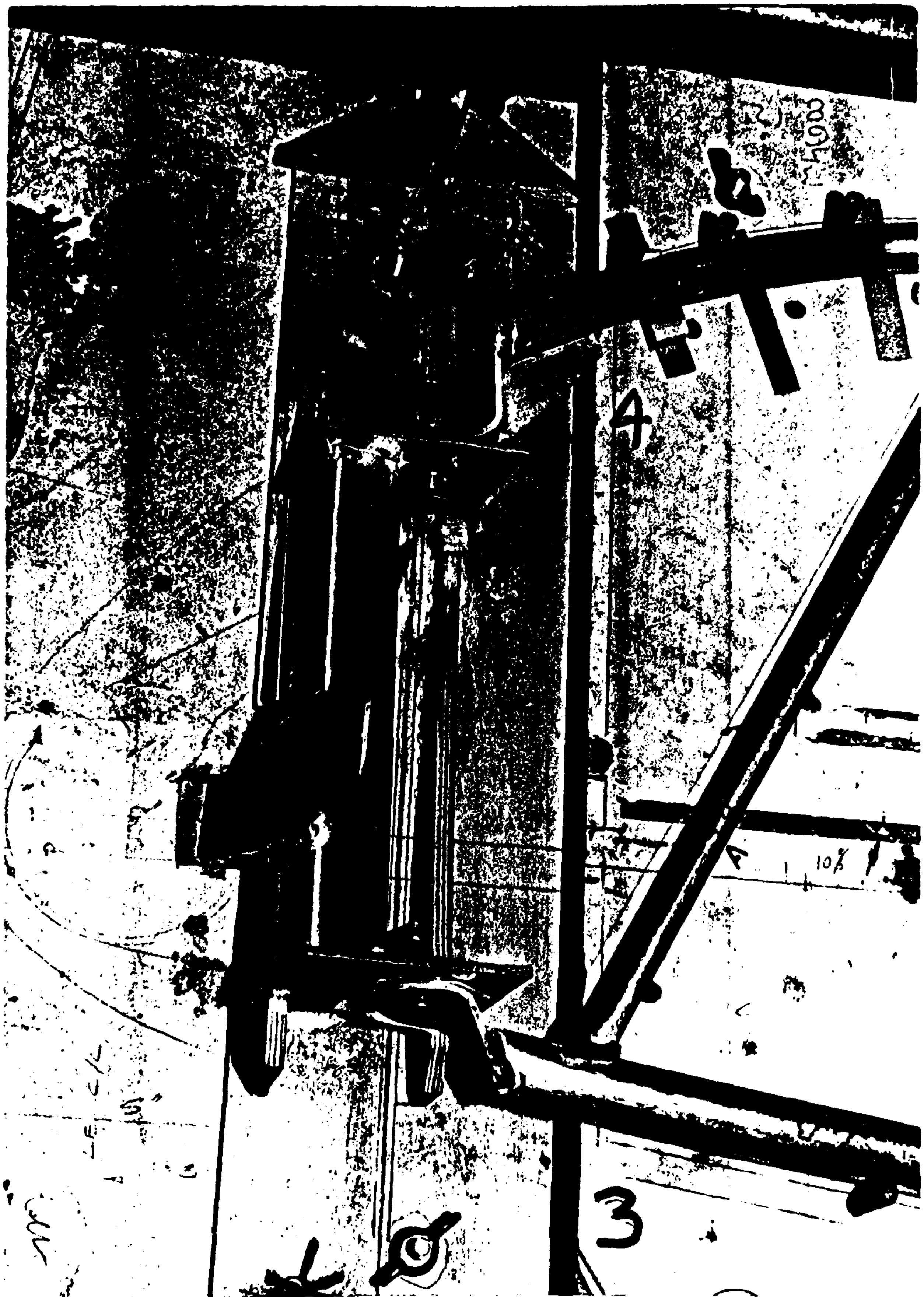


FIG. 13. FORWARD RIB HINGED JOINT.

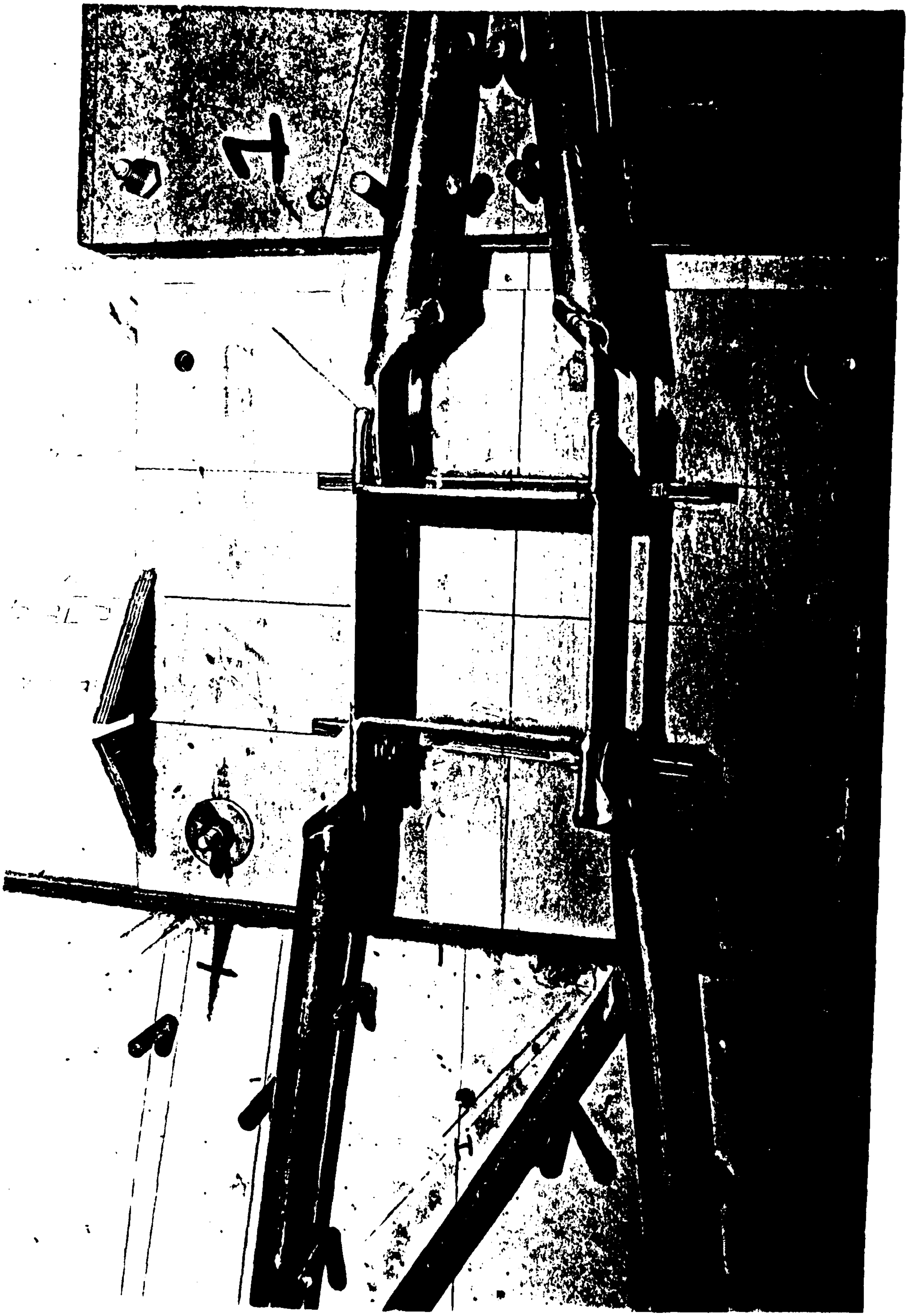


FIG. 14. RIB AFT HINGED JOINTS.

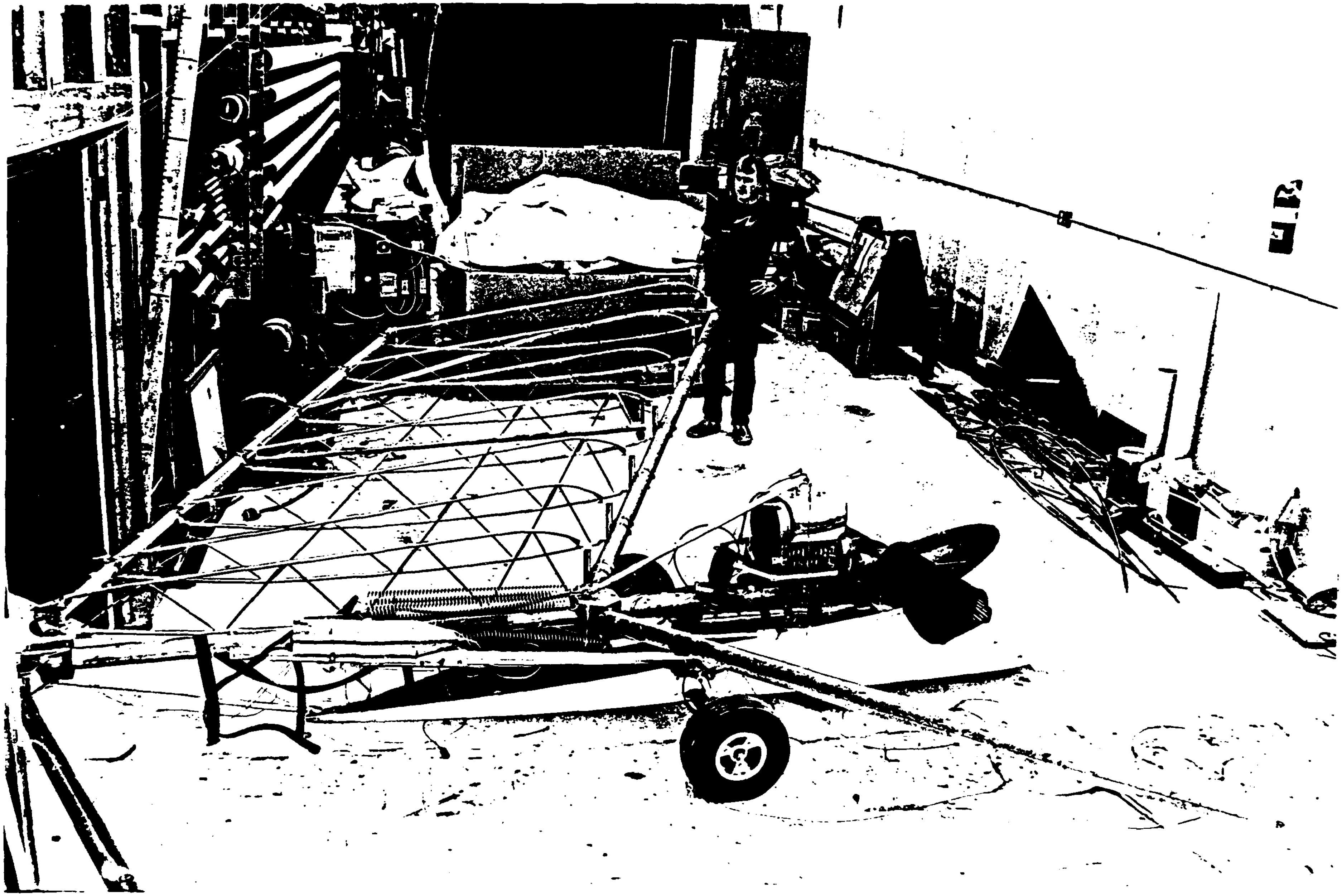


FIG. 15. FOLDING RIBS INSTALLED ON LEFT HAND SIDE
WING EXTENDED - SAIL REMOVED

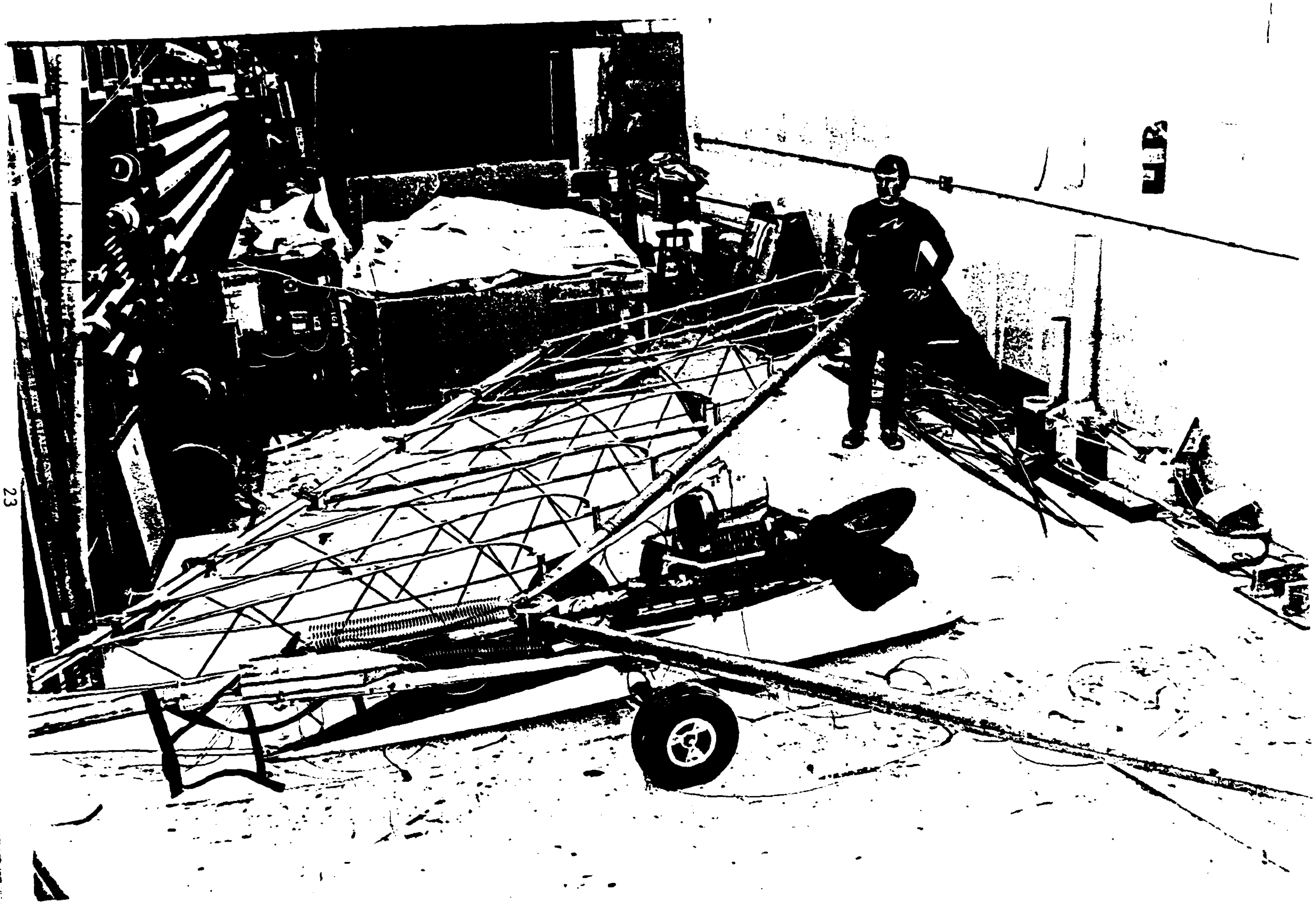


FIG. 16. WING PARTIALLY FOLDED - SAIL REMOVED - SIDE VIEW

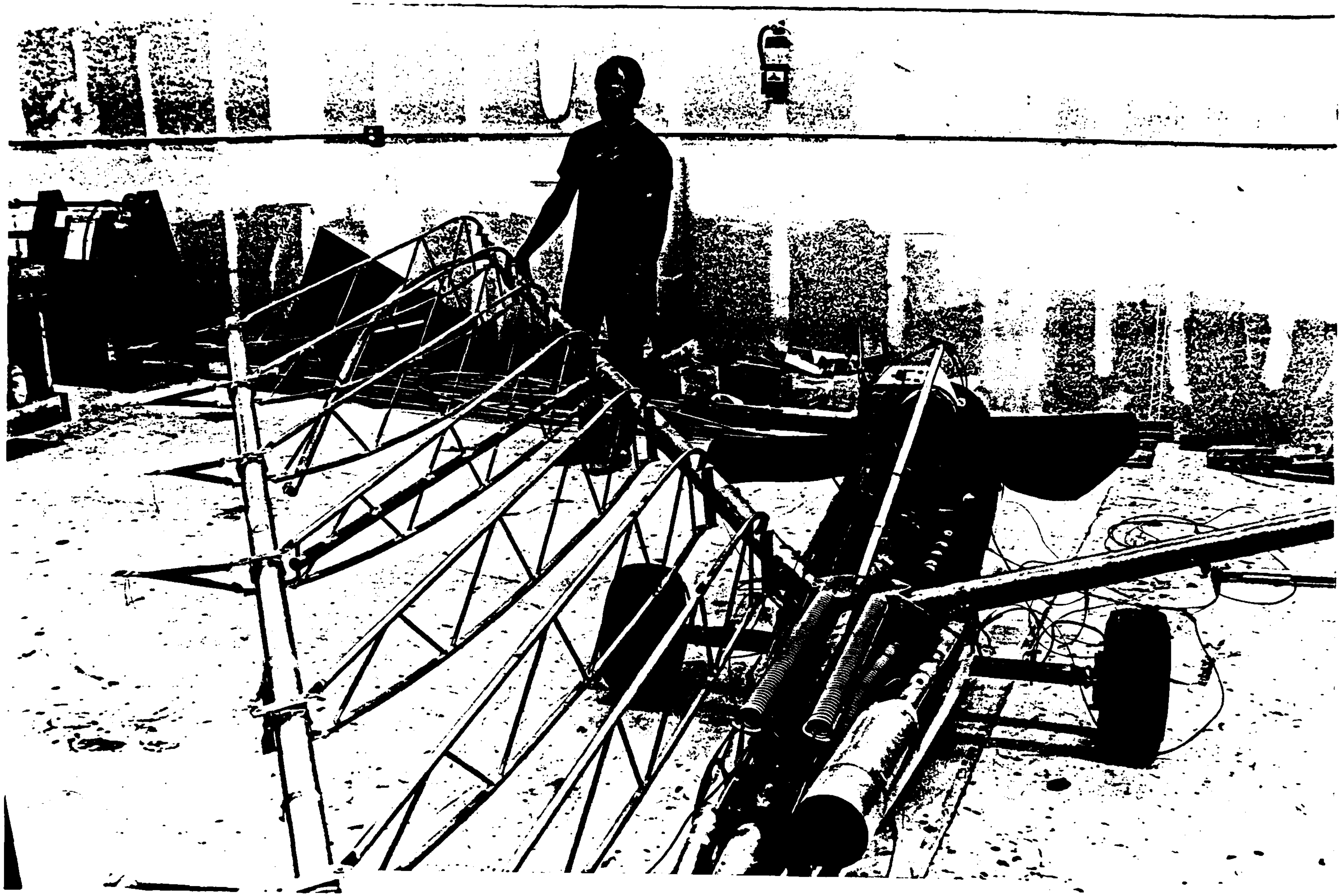


FIG. 17. WING PARTIALLY FOLDED - SAIL REMOVED - REAR VIEW

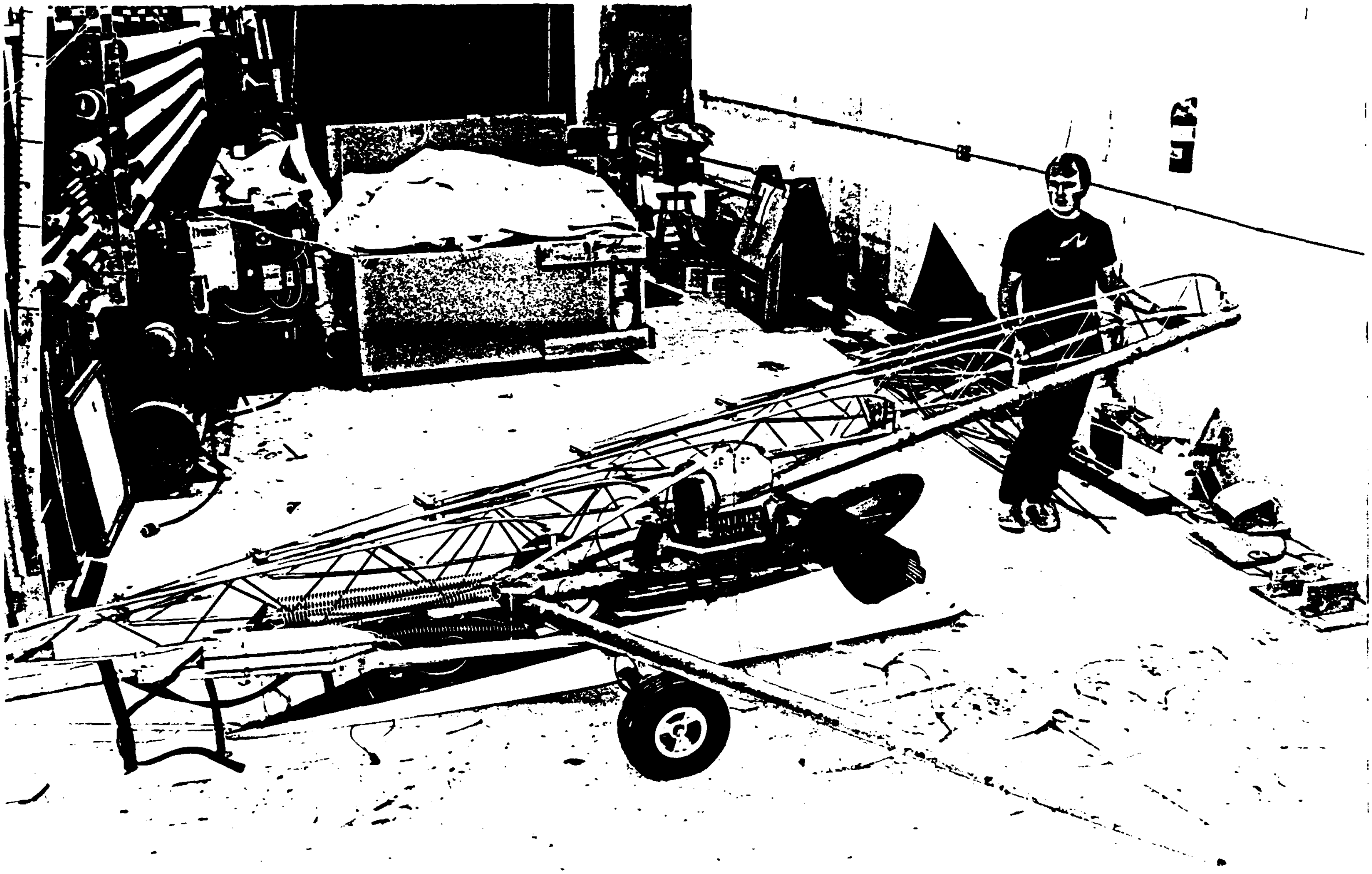


FIG. 18. WING FULLY FOLDED - SAIL REMOVED

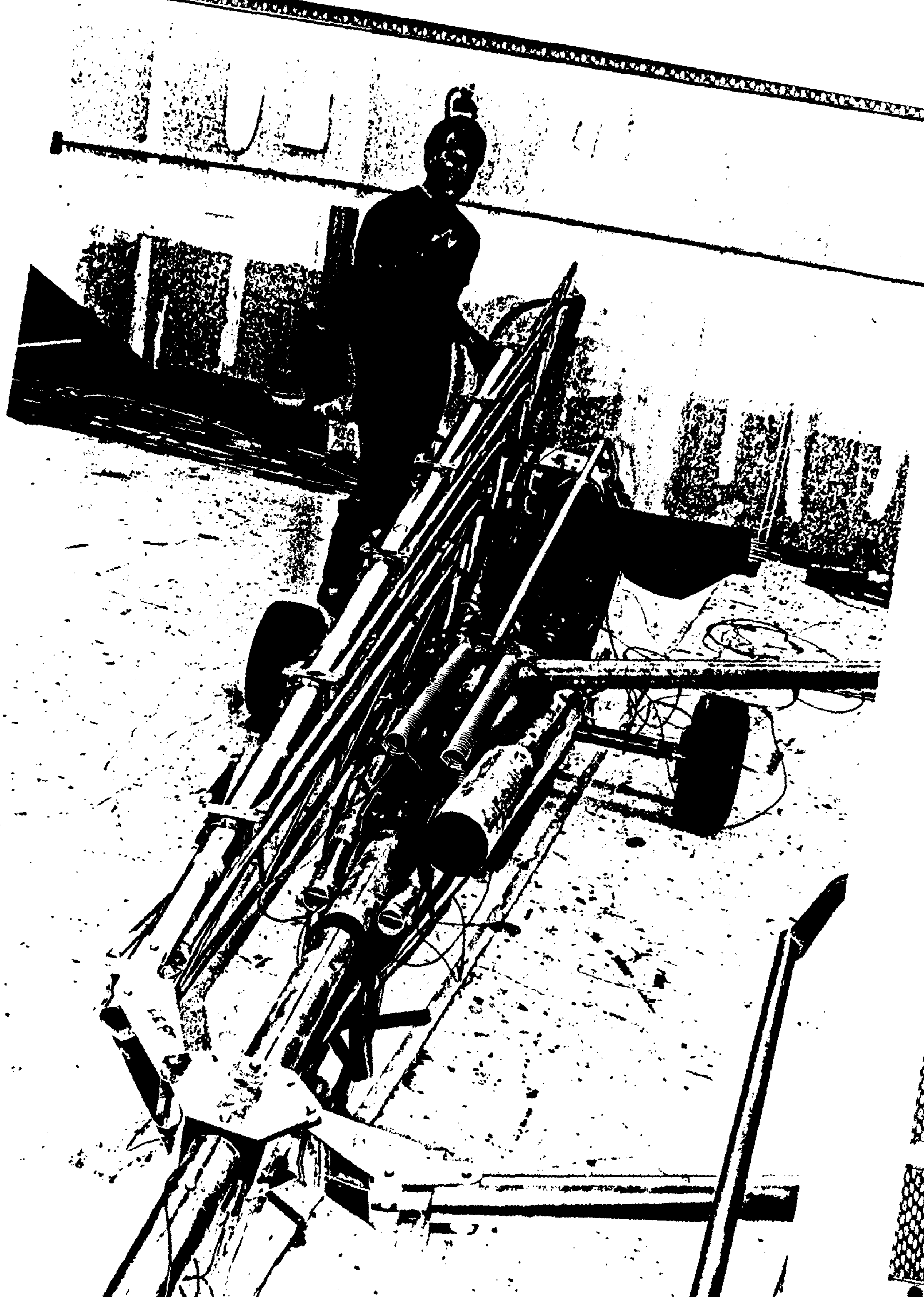


FIG. 19. WING FULLY FOLDED - SAIL REMOVED - REAR VIEW

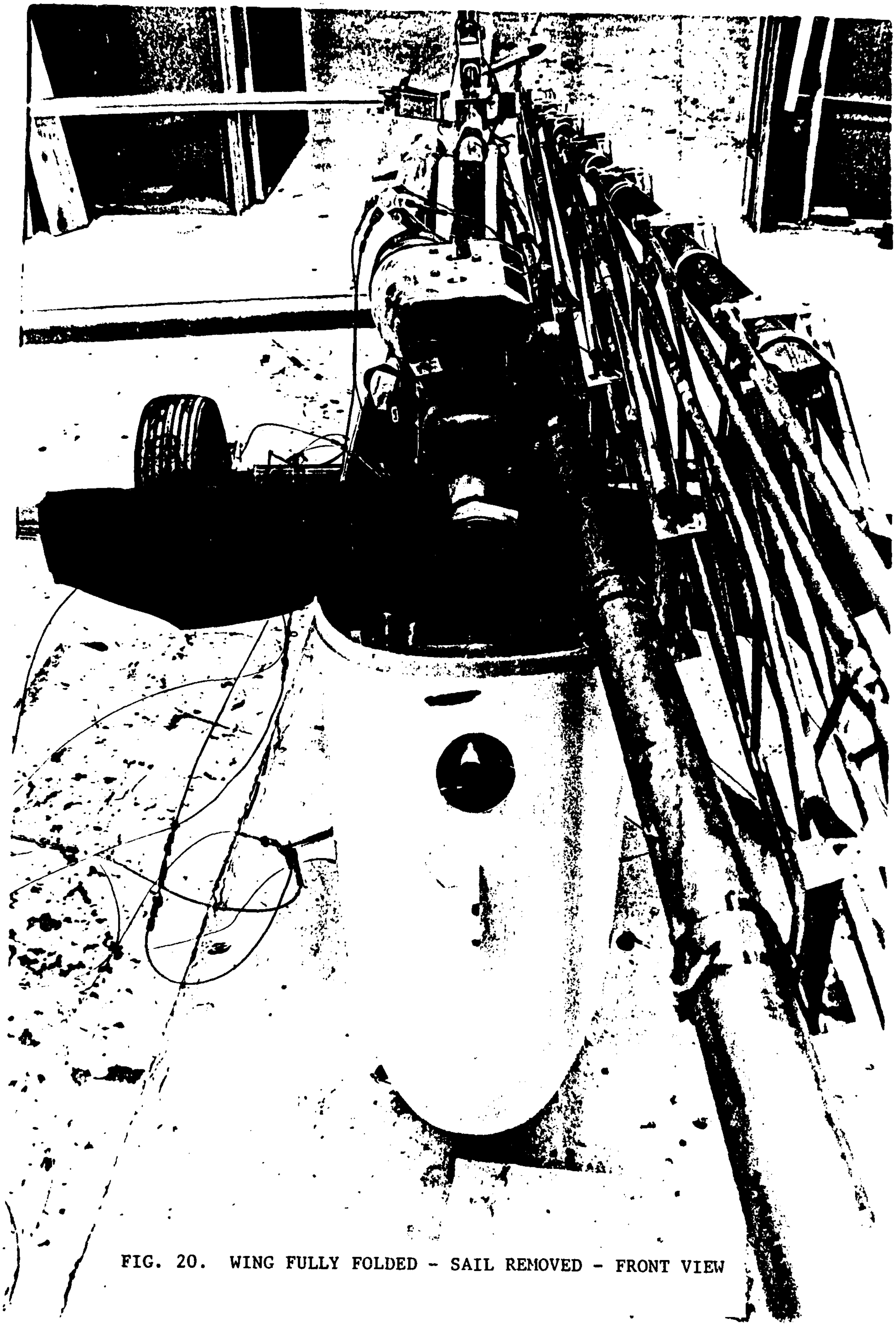


FIG. 20. WING FULLY FOLDED - SAIL REMOVED - FRONT VIEW

FIG. 21. PARTIALLY FOLDED WING WITH COVERING INSTALLED
(NOTE TRAILING EDGE EXTENSIONS PULLED FROM SAIL)

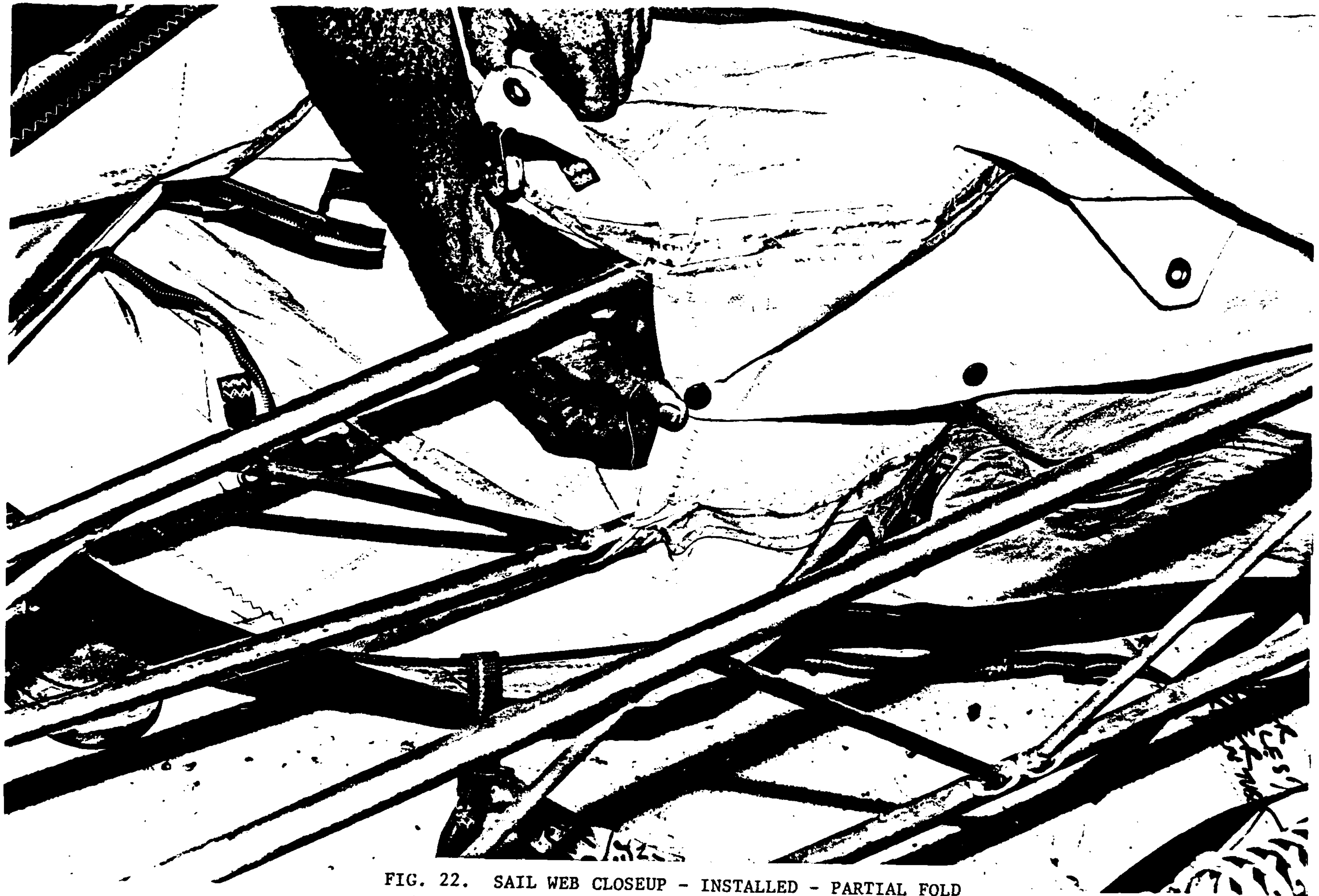


FIG. 22. SAIL WEB CLOSEUP - INSTALLED - PARTIAL FOLD
(NOTE WEB TENSION CREATED BY DIAGONAL SAIL TENSION
WHICH PULLS WEB OUTBOARD AGAINST ADJACENT RIB).

FIG. 23. RIB ATTACHMENT TO TRAILING EDGE SPAR

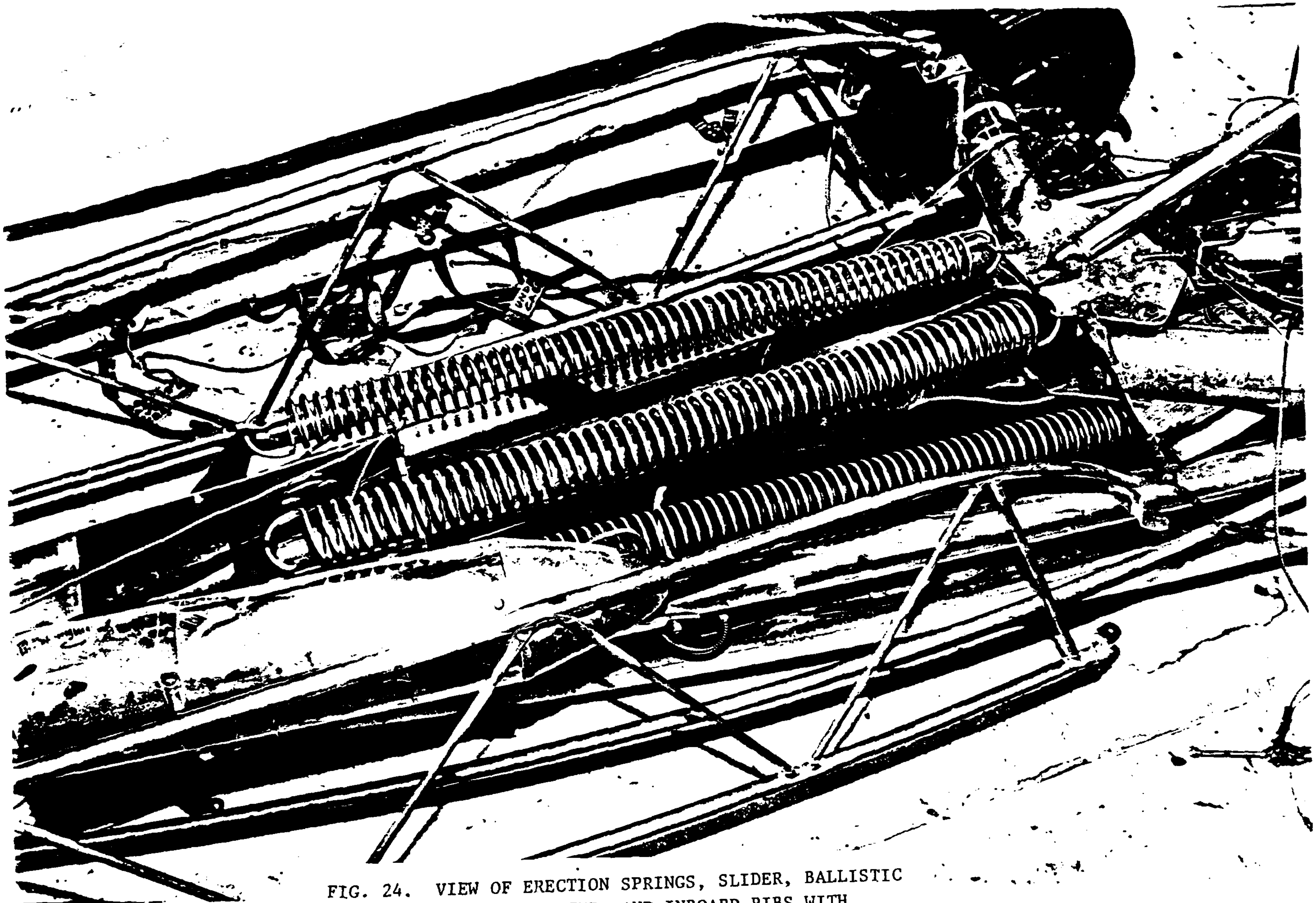


FIG. 24. VIEW OF ERECTION SPRINGS, SLIDER, BALLISTIC PARACHUTE CANNISTER, AND INBOARD RIBS WITH WINGS OPEN BUT FUSELAGE FOLDED.

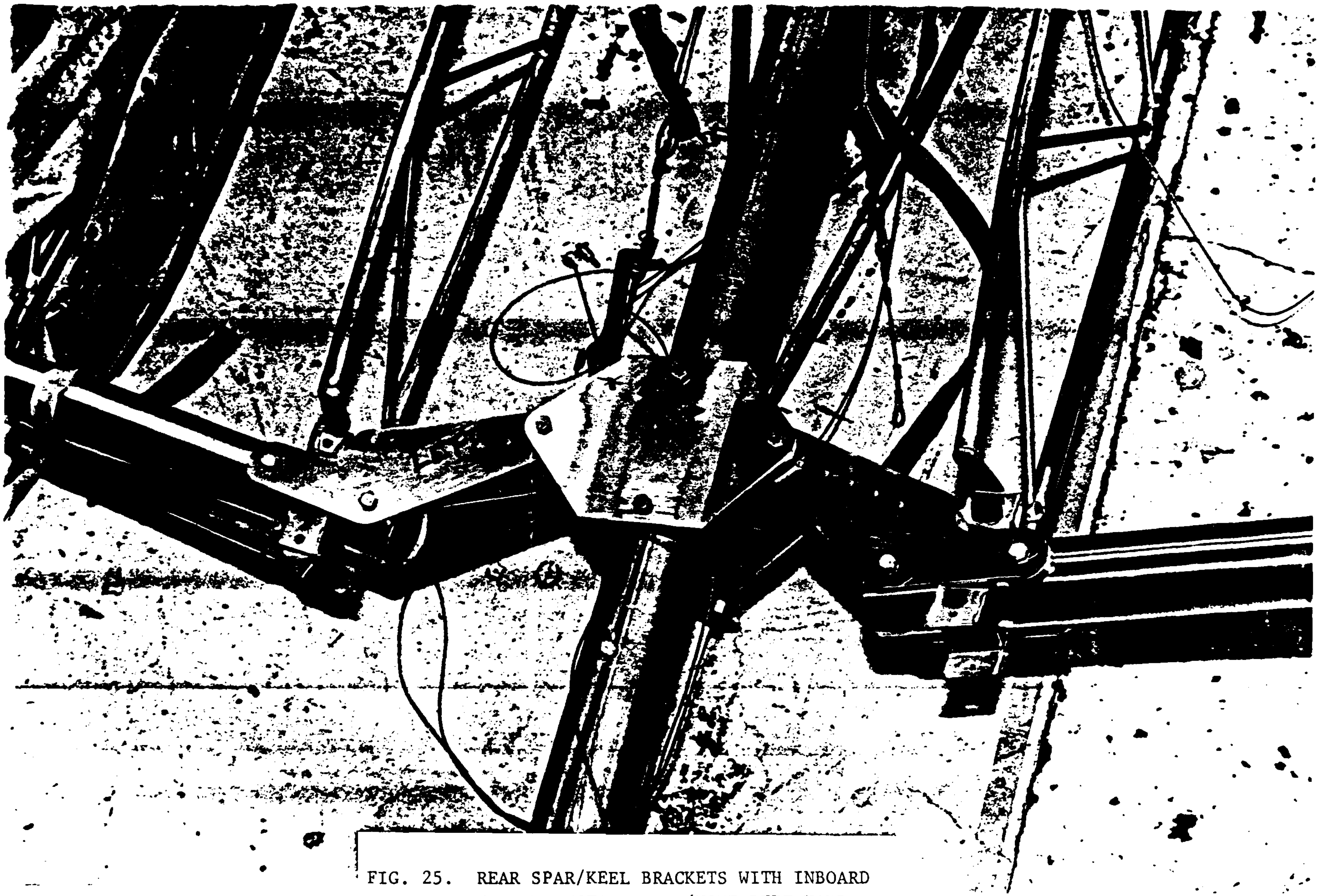


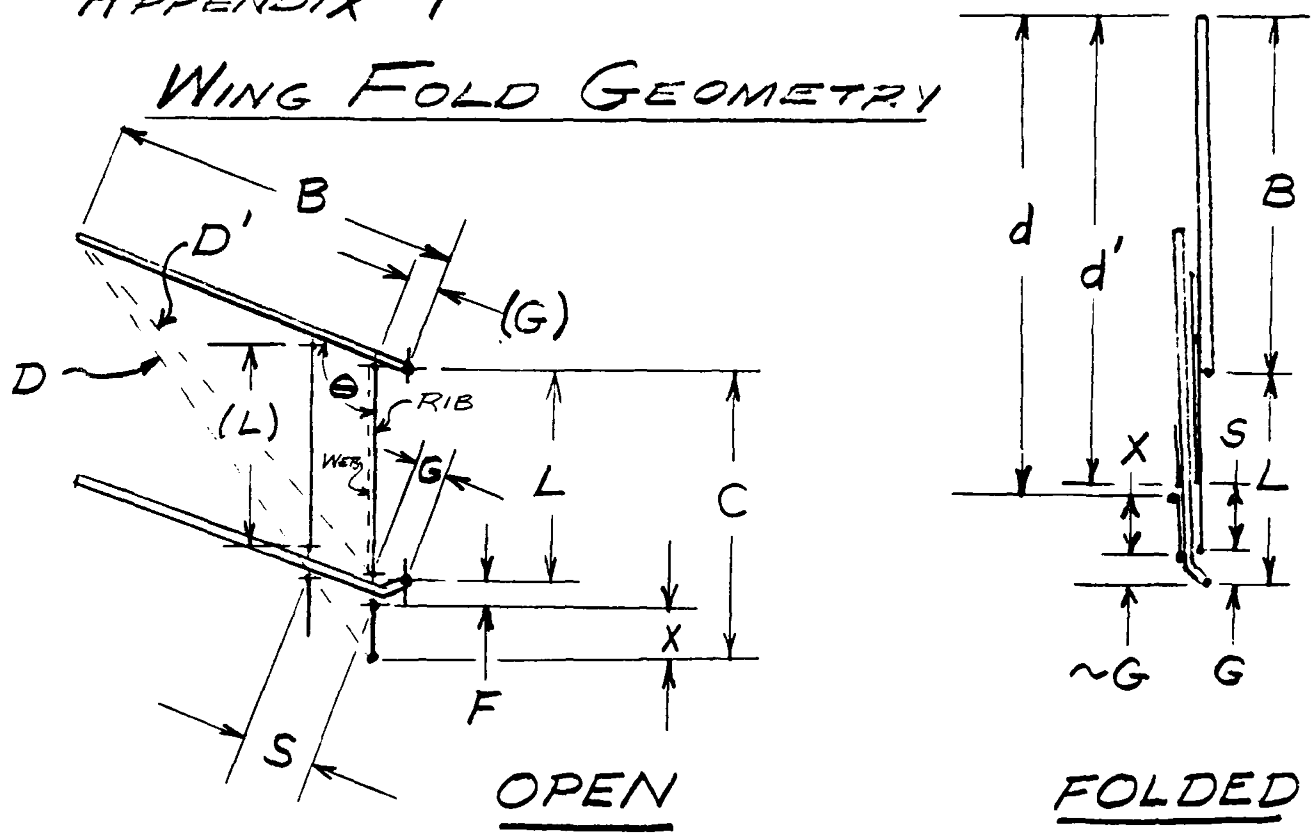
FIG. 25. REAR SPAR/KEEL BRACKETS WITH INBOARD RIBS PARTIALLY INSTALLED - (NOTE LEFT HAND TRAILING EDGE RIB FOLDED OUTBOARD).

Appendix 1

WING FOLD GEOMETRY

APPENDIX I

WING FOLD GEOMETRY



EFFECT ON DIAGONAL LENGTH:

FOR WING TO FOLD & REMAIN ATTACHED AT TRAILING EDGE;

$$D \geq d(1+\delta)$$

FOR WING TO FOLD & HAVE ROOM FOR WEB TO MOVE OUTBD WITHOUT HANGING ON ADJACENT RIB;

$$D' \geq d'(1+\delta)$$

WHERE

$$D = \sqrt{(B-G)^2 + C^2 - 2(B-G)C\cos\Theta},$$

$$d = B + L - G - X, \quad X = C - L - F,$$

$$D' = \sqrt{(B-G)^2 + L^2 - 2(B-G)L\cos\Theta},$$

$d' = B + L - G - S - Z$, WHERE Z = AMOUNT WEB CAN SLIDE UP ADJACENT RIB

APPENDIX 1 (CONT'D)

AND

δ = PRACTICAL SHEAR STRAIN ALLOWABLE FOR COVERING MATERIAL (STRAIN @ 45° TO WARP + WEAVE)

FOR 3.8 OZ STABILIZED DACRON SAILCLOTH AS USED ON ROC PROTOTYPE, IT HAS BEEN FOUND THAT:

$$\delta \cong 0.0$$

THIS LOW STRAIN ALLOWABLE PREVENTS FULL COLLAPSE OF THE WING AT ITS CURRENT SPAR AND RIB SPACING.

DETERMINATION OF MAXIMUM SPAR SPACING:

TO FIND: MAX L FOR $\delta = 0.0$

CURRENT CONFIG: $B = 12'$, $\theta = 105°$
(ROOT RIB) $G = .63'$, $F = .54'$
$C = 7.9'$, $L = 6.6'$

$$D = 15.43' \; ; \quad d = B + L - G - (C - L - F) = B + 2L - G + F - C$$
$$= 2L + 4.01$$

$$\therefore \quad 15.43 \geq 2L + 4.01 \; ;$$

FOR $\delta = 0.0$, $L \leq \underline{5.71}'$ (FOR ORIGINAL L OF 6.6' δ WOULD HAVE TO BE $\geq .115$)

RECOMMEND $L = 5.6'$

FOR MIDSPAN, ASSUME $G = 6'$

then $D = 11.09'$, $d = 2L - 1.36$, $\underline{L \leq 6.22'}$

NEAR TIP, $G = 10'$

$D = 8.64'$, $d = 2L - 5.36$

$L \leq 7'$ (NO PROB)

DETERMINATION OF MINIMUM RIB SPACING:

TO FIND: MIN S FOR $\delta = 0.0$

CURRENT CONFIG: $S_{1-2} = 1.4'$ $S_{3-4} = 2.0'$

$S_{2-3} = 1.6'$ $S_{4-5} = 2.0'$

$S_{6-7} = 2.0'$

ASSUME $L = 5.6'$

RIBS 1-2:

$D' = 13.91'$, $d' = 16.97 - S - z$, $S_{1-2} \geq 3.06 - z$

ESTIMATE $z \simeq .7'$

$\therefore S_{1-2} \geq \underline{2.4'}$

RIBS 2-3:

$D' = 12.64'$, $d' = 15.57 - S - z$, $S_{2-3} \geq \underline{2.23'}$

RIBS 3-4:

$D' = 11.21'$, $d' = 13.97 - S - z$, $S_{3-4} \geq \underline{2.06'}$

RIBS 4-5:

$D' = 9.5'$, $d' = 11.97 - S - z$, $S_{4-5} \geq \underline{1.77'}$

AS CAN BE SEEN, RESPACING RIBS NEAR THE ROOT WILL RESOLVE THE PROBLEM.

CHECK FOR QUICK FIX ON CURRENT CONFIGURATION:

$L = 6.6'$

(ELIMINATE RIB #2) $S_{1-3} = \underline{3.0'}$

(RIB #4 IS SIMPLE STRUT) $Z_4 = \underline{3'}$

S_{1-3}: $D' = 14.54$, $d' = 17.97 - S - Z$; $S_{1-3} \geq \underline{2.73'}$ OK

S_{3-4}: $D' = 11.92$, $d' = 14.97 - S - Z_4$; $S_{3-4} \geq \underline{0'}$ OK

S_{4-5}: $D' = 10.29$, $d' = 12.97 - S - Z$, $\underline{S_{4-5} \geq 1.98'}$ OK

SO, ELIMINATING RIB #2, CHANGING NO. 4 BACK TO COMPRESSION STRUT WOULD FIX WEB INTERFERENCE.

ALSO, CHECK TO SEE LENGTH OF RIB EXTENSION REQ'D TO PERMIT WING FOLD (SAIL T.E. SLIDES ON EXTENSION) FOR QUICK FIX, LEAVING SPAR SPACING AT 6.6'.

RIB #1 $D = 15.43'$; $d = B + L - G - X$

$X = B + L - G - d = 17.97 - d$

$(= 18.6 - G - D)$

LET $d = D$; $\underline{X_{NEW} = 2.54'}$

RIB #3 $X = 18.6 - G - D$, $G = 3.63$, $D = 12.91$

$\underline{X_N = 2.05}$

RIB #5 $X = 18.6 - G - D$, $G = 7.63$, $D = 9.97$

$\underline{X_N = 1.00}$

Appendix 2

POTENTIAL FIXES

Appendix 2

POTENTIAL FIXES

1) Eliminate rib no. 2 on both sides, replace rib no. 4 with simple compression strut, leave webs unfastened at rib no. 2 and no. 4. Extend ribs at trailing edge by attaching arrow shafts that protrude through grommet installed in trailing edge -- approximately 2-1/2 feet at root tapering to 3" at tip. Estimated manhours = 100. Estimated cost = $6500.

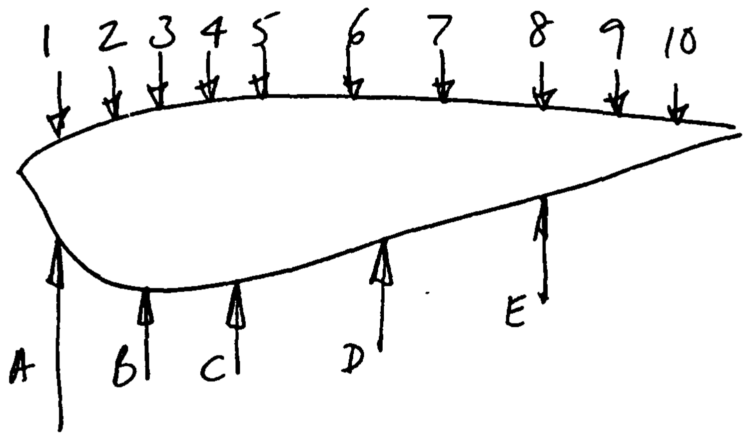
2) Relocate rear spar 1 foot forward, reduce number of ribs to five per side, redesign, test and fabricate ribs to accommodate new spar spacing. Modify sail web location to accommodate new rib spacing. Estimated manhours = 300. Estimated cost = $20,000.

Appendix 3

RIB STRUCTURAL

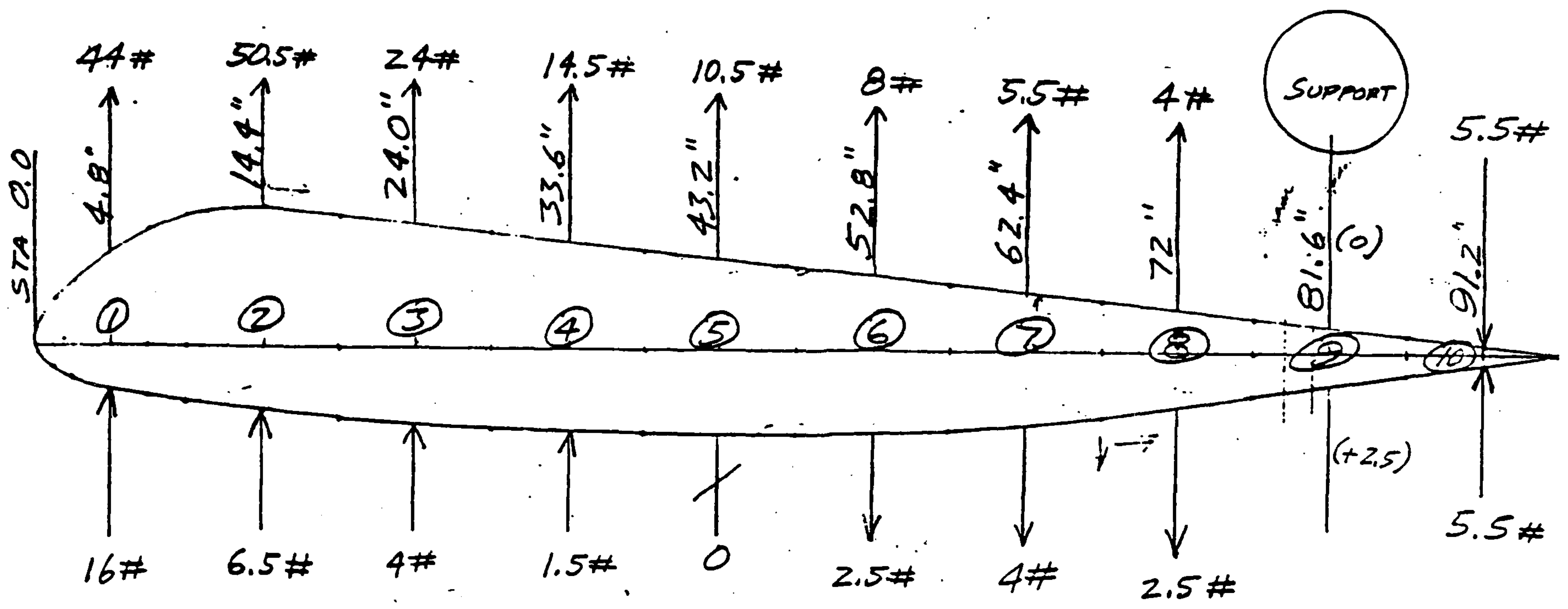
20605B. FOLDING RIB STRUCTURAL TEST. DEC 17TH 84

LEFT HAND RIB FITTED UPSIDE DOWN TO RIGHT WING SPARS. LEFT WHEEL & NOSE WHEEL BLOCKED UP UNTIL TAIL BOOM AND RIGHT SPARS BOTH HORIZONTAL AND TEST RIB VERTICAL.



WEIGHTS WERE HUNG FROM THE TOP (LOWER SURFACE) TUBE AT 10 POINTS REPRESENTING THE SUM OF THE LOADS ACTING AT THAT POINT. (LOWER & UPPER SURFACE LOADS).
MEASUREMENTS WERE TAKEN AT 5 INTERMEDIATE LOCATIONS TO DETERMINE DEFLECTION UNDER LOAD.

24" BAYS 5G $C_L = .74$



20605 RIB TEST RESULTS. DEC 17TH.

	A	1	2	B	3	4	C	5	6	D	7	8	E	9	10
CHORD	48"	4.8"	14.4"	20.0"	24.0"	33.6"	40.0"	43.2"	52.8"	60.0"	62.4"	72"	81.6"	81.6"	91.2"
0%	55 1/4"	—	—	51 7/8"	—	—	54"	—	—	55 3/4"	—	—	58 1/8"	—	—
25%	55 1/8"	15LB	15LB	51 7/8"	7 1/2LB	5LB	53 7/8"	2 1/2LB	2 1/2LB	55 1/2"	1LB	1LB	58"	—	—
50%	55 3/16"	30LB	30LB	51 7/8"	15LB	10LB	54"	5LB	5LB	55 1/2"	1LB	1LB	57 15/16"	—	—
75%	55 1/8"	45LB	45LB	51 5/8"	20LB	12 1/2LB	53 13/16"	7 1/2LB	5LB	55 3/8"	1 1/4LB	1 1/4LB	57 15/16"	—	—
100%	55 3/16"	60LB	60LB	51 5/8"	28 1/2LB	16LB	53 5/8"	11 1/4LB	6 1/4LB	55 5/16"	5LB	2 1/2LB	57 15/16"	—	—
AFTER	55 3/16"			51 13/16"			53 7/8"			55 3/8"			58"		

% LOAD DEFLECTION	A	B	C	D	E
0		25%+50%	50%+		
-1/16"	50%+100%				
-1/8"	25%+75%		25%+		25%+
-3/16"			75%+		50%+75% 100%
-1/4"		75%+100%		25%+50%	
-5/16"					
-3/8"			100%+	75%+	
-7/16"				100%+	
-1/2"					

CONCLUSION

THE RIB SUPPORTED 189.5 LBS OF DISTRIBUTED LOAD, EQUIVALENT TO 100% OF THE 5G CASE AT CL' .74. MINIMUM DEFLECTIONS WERE RECORDED AND THE RIB SHOWED NO TENDANCY TO DEFLECT SIDEWAYS UNDER LOAD.